

Experimental studies conducted on a concentrating solar collector

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Abstract

The article examines the development trends of solar energy in Uzbekistan and the issues associated with the implementation of concentrating solar technologies. A new type of concentrating solar collector has been designed specifically for the climatic conditions of Uzbekistan. The development of an experimental test facility for a heliostat-based concentrating solar collector and the determination of its technical performance through experimental studies are also considered. The advantages and disadvantages of these devices under the climatic conditions of Uzbekistan are evaluated, and the prospects for the development of solar thermal technologies are discussed and investigated. As a result, the annual total direct solar radiation incident on the proposed device was determined to be $1900 \text{ kW}\cdot\text{h}/\text{m}^2$ per year. Experimental studies showed that the proposed concentrating solar collector can produce $3,673 \cdot 10^9 \text{ J}$ of thermal energy annually per 1 m^2 of collector surface. It was demonstrated that the development and application of such devices for autonomous consumers located far from centralized energy supply systems can contribute to addressing and stabilizing current challenges associated with heat energy supply.

Keywords: Solar energy, concentrating solar technologies, solar collectors, heliostat, focal length, elevation and azimuth angles, solar radiation flux, thermal energy.

1. Introduction

Solar energy resources account for the largest share of renewable energy sources. According to data provided by the International Renewable Energy Agency (IRENA), the Sun is the ultimate source of all energy resources on Earth. The Sun emits an average of $88 \cdot 10^{24}$ calories of heat, or $368 \cdot 10^{12}$ TW of energy, every second. However, only $2 \cdot 10^{-6}$ of this energy, equivalent to approximately $180 \cdot 10^6$ TW, reaches the Earth's surface. Even this amount is approximately 5,000 times greater than the energy generated by all continuous energy-producing facilities on Earth [1].

These trends have also continued steadily in the Republic of Uzbekistan. In accordance with the resolutions of the President of the Republic of Uzbekistan, nearly 1 GW of new solar power capacity was commissioned in the country in 2024 [2]. As a result, 4.8 billion kWh of electricity was generated, 1.4 billion cubic meters of natural gas were saved, and more than 2 million tons of harmful gas emissions were reduced. At the same time, under the conditions of Uzbekistan, the high costs of concentrating solar technologies, their dependence on water resources, and dusty climatic conditions remain limiting factors for their widespread adoption.

Scientific research conducted worldwide and in Uzbekistan on the development of concentrating solar collectors was analyzed. In 1990, Austrian scientist Wolfgang Scheffler developed a reflector system for heating water in rural areas of India [3]. The device consists of a specially designed parabolic reflector with a fixed focal point that concentrates solar radiation at a single point (focus). It is a solar radiation concentrator with a fixed focal length, capable of increasing the receiver temperature to up to 200°C . The system is designed for cooking, energy generation in solar thermal power plants, and other thermal processes. Depending on its size, the efficiency of this device ranges from 55% to 60%. In addition to its simple design, the possibility of manufacturing it from inexpensive materials, high thermal output, and accurate solar tracking capability, the system also has certain disadvantages, including the requirement for a large installation area, sensitivity of optical surfaces to contamination, susceptibility to wind loads, and reduced efficiency under cold climatic conditions.

In 1960, Italian scientist Giovanni Francia proposed the single-axis Linear Fresnel Reflector (LFR) technology to improve the efficiency of energy production from solar radiation [4]. A single-axis Fresnel reflector is an optical system designed to concentrate solar energy and consists of a series of flat or nearly flat reflective

mirrors. These mirrors are positioned at specific geometric angles to direct incoming solar radiation toward a common focal line. In this system, the temperature of the heat-transfer medium can reach approximately 600 °C. Single-axis Fresnel reflectors are mainly used for industrial heat production, including steam and hot-water generation, as well as for electricity generation. The efficiency of this technology is approximately 40–45% for thermal energy production and 10–17% for electricity generation. Furthermore, the structural simplicity of single-axis Fresnel reflectors, relatively low capital costs, and ease of operation and maintenance make them competitive compared with other solar concentration systems. However, this technology also has certain limitations and disadvantages, including a relatively low concentration ratio and high thermal losses. A solar tower collector is a device designed to convert solar radiation into thermal energy and was not invented by any single individual. This technology has been gradually developed and improved over a long period through the scientific and engineering efforts of various researchers. A solar tower collector collects and concentrates solar radiation and transfers the resulting thermal energy to a heat-transfer medium such as water or air. Solar tower collector systems are widely used in the residential sector for domestic hot-water supply and space heating, in agriculture for drying agricultural products and providing process heat, as well as in various industrial technological processes. The efficiency of solar tower collector systems generally ranges from 40% to 70%, enabling a significant portion of solar energy to be converted into useful thermal energy [5]. At the same time, this technology is characterized by fuel-free operation, the absence of harmful emissions, and high energy efficiency. However, its main limitations include dependence on direct solar radiation, sensitivity to weather conditions, and relatively high initial installation costs.

The Great Solar Furnace of Asia is unique in the Asian region and was commissioned in 1987. Only two facilities of this type exist worldwide, the first of which is located in France. The Great Solar Furnace is used to study the physical properties of various materials and for their processing by concentrating solar radiation to extremely high temperatures. In this large-scale scientific and technological complex, the concentration of solar radiation can produce temperatures of up to 3000–4000 °C. The facility consists of a parabolic mirror, a concentrator system, a working chamber, and an automatic solar-tracking mechanism. Although the Great Solar Furnace operates without fuel and does not cause direct environmental pollution, its main disadvantages include its dependence on climatic conditions, operation only during daylight hours, and high initial construction costs [6].

2. Material and methods

A new-design concentrating solar collector has been developed for the climatic conditions of Uzbekistan. The concentrating solar collector operates as follows. Solar radiation is directed onto 60 flat mirrors, each measuring 20×60 cm, which are mounted on four metal profiles at an optimal opening angle ξ_i by means of hinges that allow the mirrors to rotate in different directions about their axes. The metal profiles are fixed to metal frames mounted on the metal housing at an angle of 60° through bearings and braking couplings. The reflected solar radiation from the flat mirrors is directed toward a reflecting heliostat installed on the metal housing at an angle of 45° relative to the horizontal axis and having a focal length f_i . The heliostat reflects the radiation at an angle of 90° toward a water tank, heating the water from 60 °C to 250 °C depending on variations in solar radiation. In this system, stepper motors installed on the metal frames and connected to the metal profiles rotate the flat mirrors through an angle β_i , taking into account the annual solar declination angle. A direct-current motor attached to the metal housing and wheels drives the wheels according to the daily solar azimuth angle γ_i . The metal housing is mounted on a support base through a bearing, allowing it to rotate about its own axis. The stepper and direct-current motors are controlled and adjusted by a controller and driver according to the solar trajectory, taking into account the geographical coordinates of the installation site and the solar declination and azimuth angles. The electrical power supply of the system is provided by photovoltaic solar panels. The electrical energy generated by the photovoltaic panels is transmitted via cables to a charge controller installed in the electrical control cabinet. The generated electrical energy is stored in battery accumulators and supplied to the electrical components of the system as required. Figure 1 shows the general view of the experimental prototype of the concentrating solar collector [7].



Figure 1. General view of the experimental prototype of the concentrating solar collector.

To improve the optical and energy performance of the concentrating solar collector, it is essential to ensure the accurate positioning of each flat mirror relative to the focal length. For this purpose, the opening angles of the flat mirrors on the metal profiles were determined based on theoretical calculations. The mathematical expression describing the dependence of the optimal opening angle of each flat mirror on the collector design parameters is given as follows:

$$\operatorname{tg}(\xi_{(opt)i}) = -\operatorname{tg}(\gamma_i + \Delta\alpha_i) + \sqrt{1 + \operatorname{tg}^2(\gamma_i + \Delta\alpha_i)} \quad (1)$$

where, γ_o – is the apparent angle of the Sun relative to the Earth, $\Delta\alpha$ – is the accuracy of the reflecting surface fabrication, $i=1;2;3;4$ – is the number of rows.

The focal length of the flat mirrors is determined using the following expression:

$$f_i = \frac{Y_i}{2\operatorname{tg}\left(\frac{\xi_{(opt)i}}{2}\right)} \quad (2)$$

$$a_i^2 = f_i^2 + Y_i^2 = f_i \sqrt{1 + 4\operatorname{tg}^2\left(\frac{\xi_i}{2}\right)} \quad (3)$$

$$\frac{Y_i}{a_i} = \sin(\xi_{(opt)i}) \quad (4)$$

$$a_i = \frac{Y_i}{\sin(\xi_{(opt)i})} \quad (5)$$

where, f – the focal length, Y – the distance from each flat mirror to the central heliostat, ξ_{opt} – the optimal opening angle of each flat mirror.

Figure 2 presents a schematic diagram of the geometric dimensions of the concentrating solar collector.


$$L = f_i \cdot \frac{\left(1 + tg^2\left(\frac{\xi_i}{2}\right)\right)^2 tg(\gamma_i + \Delta\alpha_i)}{1 - tg^2\left(\frac{\xi_i}{2}\right) - 2tg\left(\frac{\xi_i}{2}\right) \cdot tg(\gamma_i + \Delta\alpha_i)} \cdot \sqrt{1 + tg^2\left(\frac{\xi_i}{2}\right)} \quad (6)$$

Flat mirror number	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
$\xi_{(opt)}$	16° 15′	14° 43′	12° 52′	11° 19′	10° 11′	8° 07′	5° 48′	0	5° 48′	8° 07′	10° 11′	11° 19′	12° 52′	14° 43′	16° 15′

$$E_y = I_y R_z S_f \sum_{i=1} \cos(\frac{\xi_i}{2}) \cos(\mu) \quad (7)$$

The total solar radiation is a function of solar angles such as the angle of incidence of solar radiation on the surface (θ), solar declination angle (δ), solar hour angle (ω), surface azimuth angle (orientation) (γ), latitude of the greenhouse location (ϕ), and surface tilt angle (β). The total solar radiation is determined using the following equation based on the isotropic model:

$$I_{\gamma} = R_b \cdot I_b + I_d \cdot R_d + \rho_q \cdot I_H \cdot R_q \quad (8)$$

The sunrise and sunset hour angles of the Sun vary depending on the tilt angle and azimuth angle. The geometric factor (tilt coefficient) R_b , which depends on the two-hour angles ω_1 and ω_2 ($\omega_2 > \omega_1$), is determined using the following equation:

$$R_b = \frac{\int_{\omega_1}^{\omega_2} \cos \theta_i d\omega}{\int_{\omega_1}^{\omega_2} \cos \theta_z d\omega} = \frac{a}{b} \quad (9)$$

$$a = (\sin(\delta) \cdot \sin(\varphi) \cdot \cos(\beta) - \sin(\delta) \cdot \cos(\varphi) \cdot \sin(\beta) \cdot \cos(\gamma)) \cdot (\omega_2 - \omega_1) \cdot \frac{\pi}{180} + (\cos(\delta) \cdot \cos(\varphi) \cdot \cos(\beta) + \cos(\delta) \cdot \sin(\varphi) \cdot \sin(\beta) \cdot \cos(\gamma)) \cdot (\sin(\omega_2) - \sin(\omega_1)) - (\cos(\delta) \cdot \sin(\beta) \cdot \sin(\gamma)) \cdot (\cos(\omega_2) - \cos(\omega_1)) \quad (10)$$

$$b = (\cos(\delta) \cdot \cos(\varphi)) \cdot (\sin(\omega_2) - \sin(\omega_1)) + (\sin(\delta) \cdot \sin(\varphi)) \cdot (\omega_2 - \omega_1) \cdot \frac{\pi}{180} \quad (11)$$

According to the Liu and Jordan model, the coefficients R_d and R_g are determined using the following formulas

$$R_d = \frac{1 + \cos(\beta)}{2} \quad (12)$$

$$R_g = \frac{1 - \cos(\beta)}{2} \quad (13)$$

To determine the thermal efficiency of the system, the total energy incident on the heliostat is calculated using the following formula:

$$Q_\Sigma = E_y S_{fm} R_z R_p \sigma \quad (14)$$

where, S_{fm} – total area of the radiation-reflecting surface of the system, R_z – reflectivity coefficient of the mirror, R_p – absorptivity coefficient of the radiation-receiving surface, σ – a factor accounting for the characteristics of the system structure, the solar-tracking mechanism, and the radiation-reflecting surface.

3. Result and Discussion

The metal profiles are attached to the metal housing by means of braking couplings and stepper motors. The function of the braking couplings is to ensure the fixed position of the stepper motor shafts, which rotate the metal profiles through an angle β_i , taking into account the annual solar declination angle. The stepper motors rotate the metal profiles through an angle β_i according to the annual solar declination angle. The stepper motors are controlled and adjusted באמצעות a control controller and drivers. The direct-current (DC) motor is attached to the metal housing and wheels and moves the system using the wheels according to the daily solar azimuth angle γ_i . The DC motor is controlled by a controller and driver from 08:00 to 18:00 daily, taking into account the variation in the solar azimuth angle γ_i . In this case, the azimuth angle changes by 15° every hour. Battery accumulators are used to provide the electrical power supply to the system.

The proposed system has dimensions of 3×4 m and consists of 60 flat mirrors, each measuring 20×60 cm, arranged in four rows and mounted on metal profiles. The focal lengths of the flat mirrors in the respective rows are 4.52, 5.06, 5.17, and 5.59 m. The annual total direct solar radiation incident on the proposed system is $1900 \text{ kWh/m}^2 \cdot \text{year}$. Taking this value into account, the amount of thermal energy that can be obtained using the concentrating solar collector is $26,448 \cdot 10^9 \text{ J}$. The proposed concentrating solar collector can produce $3,673 \cdot 10^9 \text{ J}$ of thermal energy per year per 1 m^2 of surface area.

A new design of a concentrating solar collector has been developed for the climatic conditions of Uzbekistan. The annual total direct solar radiation incident on the proposed system was determined to be $1900 \text{ kWh/m}^2 \cdot \text{year}$. It was established that the proposed concentrating solar collector can produce $3,673 \cdot 10^9 \text{ J}$ of thermal energy annually from a surface area of 1 m^2 . The development and application of such systems for autonomous consumers located far from centralized energy supply networks can contribute to addressing current challenges associated with heat energy supply and improving the sustainability of energy provision.

Reference

- [1] <https://www.irena.org/News/articles/2023/Nov/IRENA-the-architect-of-the-energy-transformation>
- [2] <https://www.gazeta.uz/oz/2026/01/05/energy/>
- [3] Rupesh J. Patil Comparisom of performance analysis of Scheffler reflector and model formulation. 2011, pp.1335-1339 [Shefler comparisonofperformanceIJST.pdf](#)

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- [4] Mohaymen Alutbi Thi Qar University. Linear Fresnel Reflector. June 2020.
https://www.researchgate.net/publication/342163823_Linear_Fresnel_Reflector_LFR
- [5] Omer K. Ahmed, Sameer Algburi, Zaid H. Ali, Amer K. Ahmed, Hawazen N. Shubat Hybrid solar chimneys: A comprehensive review 2022, pp.438-460
https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf?utm_source=chatgpt.com
- [6] Jurayev, T.D. Solar Thermal and Energy Devices. Textbook, 2022.
- [7] Safarov, A.B., Juraqulov, A.A., Qo'ziyev, Z.E., & Mamedov, R.A. "Concentrating Solar Collector." Invention Patent No. IAP 7982, Ministry of Justice of the Republic of Uzbekistan, March 11, 2025.